HEAT TRANSMISSION IN CONDENSER COILS

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Heat Transmission in Condenser Coils

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A THESIS

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PREFACE.

We present this thesis to the President and Faculty of Armour Institute of Technology as representing our study of this specific problem.

We realize that we have only touched its many phases but hope that our record of work done may be deemed worthy to be used as a foundation for other work on this problem.

We wish to express our thanks to Professor McCormack for his many suggestions and his able direction of our work. We also wish to express our thanks to Professor Peebles for his assistance.

Walter J. Anderson
Lyman D. Judson.

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OBJECT OF THESIS.

The following experiments, preliminary in nature, were undertaken with two objects in view; (1) to determine if the transfer of heat from steam to a metal surface corresponded to the existing formula of a gas, in which K is equal to $.000028(2+\sqrt{V})$, or whether it corresponded to the formula of a liquid, in which K is equal to $.000028(300+180\sqrt{V})$; (2) to determine if the methods of experimentation used were applicable and desirable for a more extensive investigation of this subject, to develop a new formula for conductivity applicable to steam.

INTRODUCTION.

In a flow of heat from a medium, gaseous or liquid, in contact with a metal surface, to a medium in contact with the opposite side of the metal, there are three resistances to be overcome. First, the film resistance of the heating medium against the metal surface, second, the resistance through the metal, and third, the film resistance of the medium on the opposite side of the metal. In the case of liquids in contact with metal surfaces, it will be found that resistance of the liquid films are considerable as compared with the resistance of the metal itself.

If the heating medium is steam, there are two possibilities to consider. First, if steam is superheated, it behaves like a gas and the existing formula for heat transfer from gas to metal may be applied; that is,

$$K \text{ equals } .000028(2+\sqrt{V}).$$

Second, if the steam is not superheated, but the vapors carry moisture, which wet the surface of the metal and form a film of infinitessimal thickness, there the transfer conductivity of a liquid to a metal may be applied; that is

$$K \text{ equals } .000028(300+180\sqrt{V}).$$

This second possibility does not consider the transfer of heat from the gaseous steam to the liquid film, nor the transfer of heat through the liquid film. These transfers can not readily be determined experimentally.

The film resistances on either surface of the metal, depends both on the nature of the medium, and on the relative movement or agitation between the medium and the surface. Therefore, it is necessary to determine the mean velocity and the nature of each medium. Owing to the difficulty in obtaining a mean velocity for the steam, which in the present experiments was fully condensed within the tube; it was decided to use the entrance velocity and obtain a heat flow based on this assumption.

DESCRIPTION OF APPARATUS.

The heat transmission tube consists of a standard one inch brass pipe, placed centrally within a standard three inch brass pipe by means of brass caps screwed on at each end of the three inch pipe. The one inch pipe is soldered to one of the caps, while a stuffing nut placed in the other cap allows for the expansion of the one inch pipe.

The trap for the condensed steam consists of a six inch length of the three inch pipe with caps screwed on both ends. The whole trap is screwed on to the end of the one inch steam tube, centrally through one cap. A wrought iron baffle plate, a quarter inch in thickness, is placed vertically in the center of the trap. The bottom of this baffle plate is sheared so as to allow a one inch vertical opening. The other cap is provided with a one inch nipple to permit the escape of excess steam. A U tube, consisting of three-quarters inch pipe and twelve inches long, is screwed into the bottom of the trap at the center. The whole apparatus is covered with a one inch thickness of plastic asbestos.

The cooling water, tapped from the main line to insure constant flow, enters the three inch pipe at (4) (see

blue print), circulates around the one inch pipe and leaves the tube at point (5). Its flow is counter-current to that of the steam within the one inch pipe.

The steam, tapped from the main line, enters a separator, where the mechanically suspended water is separated out and withdrawn and the pressure reduced to atmospheric pressure. The comparatively dry steam passes through a three-quarters inch pipe, which is heated by an electric furnace to a superheat. The superheated steam then enters the heat transfer tube. Here it is condensed and due to the inclination of the whole apparatus, the condensed steam flows into the trap. On entering the trap, any uncondensed steam strikes the baffle plate and the mechanically suspended water separates out, while the uncondensed steam passes under the baffle plate and out through the steam exit at (11). The condensed steam flows out through the U tube and into a weighing tank.

The U tube serves to control the outflow of the condensed steam and to maintain a constant level at the bottom of the trap. This level is to allow the steam to pass under the baffle plate and to prevent its flow out through the U tube.

DETAILS OF APPARATUS.

(See blue-print)

(1) 1" brass pipe 10'-1¾" long. Outer diameter 1-5/16" Inner diameter 1-1/16".

(2) 3" brass pipe. Outer diameter 3-15/32". Inner diameter 3-1/16".

(3) Trap. Baffle plate in center.

(4) ~~Cooling water inlet.~~ Condensed steam outlet.

(5) ~~Cooling water outlet.~~ Air inlet

(6) Steam inlet.

(7) Steam separator.

(8) Electric heater.

(9) Condensed steam reservoir. ([illegible] 8)

(10) Condensed steam outlet. ([illegible])

(11) ~~Uncondensed steam outlet.~~ [illegible]

(12) Stuffing nut.

(13) ~~1~~" asbestos lining. 2"

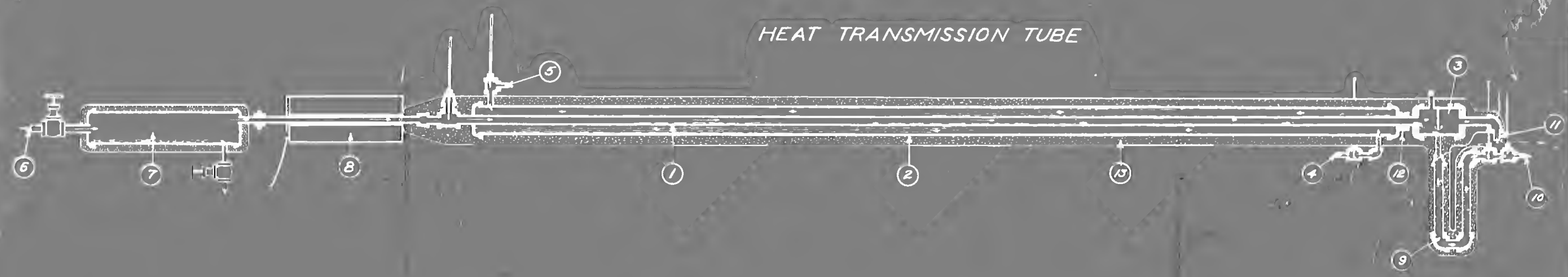
A equals mean surface area of 1" brass pipe equals

2930.35 sq. cm.

a equals area of opening of 1" brass pipe equals 5.72 sq.cm.

b equals area of opening between inside of 3" pipe and outside of 1" pipe equals 38.795 sq. cm.

t_b equals thickness of 1" brass pipe equals .3175 cm.


HEAT TRANSMISSION TUBE
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MEASUREMENTS.

The temperature of the cooling water, entering and leaving, was taken with a mercury thermometer, reading directly to degrees Centigrade and easily estimated to tenths of a degree. The thermometers were passed directly through rubber stoppers and were in direct contact with the water.

The temperature of the steam was taken with mercury thermometers, graduated in degrees Centigrade. They were passed through rubber stoppers, so that the bulbs were in direct contact with the steam at entrance, and the condensate at exit.

The velocity of the cooling water through the tube was obtained by weighing the total amount discharged in a given period of time. The time was measured by a stop watch. The scales used were ordinary platform scales. The total amount used during the run was computed from the mean result of the various weights.

The condensate was collected and weighed. From this weight the volume of entering steam was calculate d by the gas law, $V:V_1::T:T_1$.

since superheated steam obeys the gas laws.

PROCEDURE OF EXPERIMENTS.

Preliminary to starting a run, the cooling water and steam were turned on until conditions became constant and no excess steam issued from the exit of the trap. This insured the total condensation of the steam within the heat transfer tube. The rate of the cooling water was regulated to the amount of steam used, in order that the temperature of both the condensate and the exit cooling water would be under 50 degrees Centigrade. This was done to prevent any loss by vaporization.

After conditions had become constant, the readings were taken every ten minutes for a period of one hour. These readings included entrance and exit temperature of cooling water, entrance temperature of steam, exit temperature of condensed steam, and weight of cooling water discharged per minute. At end of the run the weight of condensed steam was determined. The room temperature and barometer readings were taken for each run.

SAMPLE CALCULATIONS.

Data.

Cross sectional area of steam entrance equals 5.72 sq. cm.

Cross sectional area of water pipe equals 38.8 sq. cm.

Degrees Centigrade x 1.8 equals Degrees Fahrenheit.

One pound of steam at 100 deg. C. equals 26.79 cu. ft.

T_1 equals 109.8 C. T_4 equals 35.6

T_2 equals 32.3 W_s equals 57.6 lbs.

T_3 equals 12.6 W_w equals 1698. lbs.

1 cu. ft. equals 28,317 cc.

Calculations.

Volume of 1 pound steam at 109.8 C.

$26.79/V$ equals $373/382.8$

V equals 27.28 cu. ft.

Velocity of steam per second in centimeters.

$$\frac{27.28 \times 57.6 \times 28{,}317}{3600 \times 5.72} \text{ equals } 2180. \text{ cm./sec.}$$

Velocity of water per second in centimeters.

$$\frac{1698 \times 28{,}317}{62.5 \times 3600 \times 38.8} \text{ equals } 5.5 \text{ cm./sec.}$$

To determine heat content of steam.

H equals $r + Q_1 + c_p Q_2$

where $r + Q_1$ equals total heat at 212 deg. F.

C_p equals specific heat of superheated steam at constant pressure.

Q_2 equals amount of superheat.

From steam tables $r+Q$ equals 1150.4 B.T.U.

C_p equals .49

Then total heat given up by one pound steam equals:

$(1150.4 + .49 \times 9.8 \times 1.8) - (1.8 \times 35.6)$ equals 1085.3 B.T.U.

Total heat gained by water.

$1698 \times 1.8 \times 19.7$ equals 60,200 B.T.U. per Hr.

Total heat given up by steam equals:

1085.3×57.6 equals 62, 900. B.T.U.

Calories given up by steam per second.

$\frac{62,900 \times 252}{3600}$ equals 4220.

(F_1) H equals $\frac{A \times (T_s - T_w)}{1/K_b + 1/K_w + 1/K_s}$

Where $1/K_b$ equals conductivity of brass equals 1.34

$1/K_w$ equals conductivity from metal to liquid.

$1/K_s$ equals conductivity from gas to metal.

And K_w equals $.000028(300 + 180\sqrt{V_w})$.

K_s equals $.000028(2 + \sqrt{V_s})$.

T_s and T_w are mean temperatures and A equals heating sur-

face.

Substituting, H equals:

$$\frac{2930.35 \times 50.25}{1.34 + 1/.000028(300 + 180\_\sqrt{5.5}\,) + 1/.000028(2 + \_\sqrt{2180})}$$

equals 188. calories.

(F_2) This formula is the same as F_1 except we consider steam as a liquid and use the water conductivity.

H equals:

$$\frac{2930.35 \times 50.25}{1.34 + 1/.000028(300 + 180\_/\ 5.5) + 1/.000028(300 + 180\_/\ 2180)}$$

equals 2690 calories.

(F_3) This is the same as F_2 except in the term T_s which is considered the mean between 100 and 109.8.

H equals:

$$\frac{2930.35 \times 82.45}{1.34 + 1/.000028(300 + 180\_\sqrt{5.5}) + 1/.000028(300 + 180\_/\ 2180)}$$

equals 4410. calories.

4220 - 2690 equals 1530. cal. Diff. F_W and F_2

2690 x 100/4220 equals 64.7% of correct value.

4220 - 4410 equals -190 cal. excess F_3 over F_W.

4410 x 100/4220 equals 104.5% of correct value.

NOTATION USED IN TABLES.

T_1 equals inlet temperature of steam in degrees Centigrade.

T_2 equals outlet temperature of cooling water in deg. C.

T_3 equals inlet temperature of cooling water in degrees C.

T_4 equals outlet temperature of condensed steam.

W_s equals weight of condensed steam in pounds.

W_w equals weight of cooling water in pounds.

* equals total weight per run.

V_s equals velocity of steam at entrance.

V_w, equals velocity of cooling water.

T_s equals mean temperature of steam and condensed steam.

T_w equals mean temperature of cooling water.

T_s, equals mean temperature of superheated steam.

R_s equals calories per second given up by steam.

R_w equals calories per second absorbed by cooling water.

F_1 equals calories calculated from formula F_1.

F_2 equals calories calculated from formula F_2.

F_3 equals calories calculated from formula F_3.

RUN NUMBER ONE.

Time	T_1	T_2	T_3	T_4	W_s	W_w
00	106.5	35.0	13.00	39.0		28- 5
10	107.5	33.0	12.75	38.0		28- 5
20	107.5	33.0	12.75	36.0	25- 4	28- 5
30	111.0	32.0	12.50	35.0		28- 5
40	112.0	31.0	12.50	34.5		28- 6
50	111.0	31.0	12.50	34.0		28- 6
60	113.0	31.0	12.25	33.5	32- 6	28- 4
Mean	109.8	32.3	12.60	35.6	*57.63	*1698.

RUN NUMBER TWO.

Time	T_1	T_2	T_3	T_4	W_s	W_w
00	109.5	42.0	12.2	43.0		27- 1
10	108.5	42.0	12.0	43.7		27- 2
20	110.0	43.0	12.0	42.8	42- 6	27- 0
30	110.0	42.0	12.0	43.0		27- 0
40	109.5	42.0	12.0	42.'		27- 1
50	109.5	42.0	12.0	43.8	43- 4	27- 0
60	110.5	42.0	12.0	43.8	43- 4	27- 0
Mean	110.0	42.0	12.0	43.0	*85.6	*1625.

RUN NUMBER THREE.

Time	T_1	T_2	T_3	T_4	W_s	W_w
00	120.0	27.2	14.2	28.2		24- 2
10	119.0	26.5	14.0	30.8		23-14
20	119.0	27.5	14.0	30.3		24- 0
30	121.0	28.0	13.8	30.0		24- 0
40	122.0	27.5	13.8	29.5		24- 2
50	123.0	27.0	13.2	29.0		24- 0
60	125.0	26.0	13.2	28.8		24- 0
Mean	121.0	27.2	13.7	29.5	*32.5	*1440.

RUN NUMBER FOUR.

Time	T_1	T_2	T_3	T_4	W_s	W_w
00	108.8	26.0	15.5	29.5		33-12
10	114.5	25.5	16.1	28.8		33-10
20	115.0	25.3	16.1	29.0		33-12
30	116.5	25.0	16.0	28.5		33-14
40	119.0	25.2	16.0	28.0		36- 4
50	120.0	24.8	15.8	27.8		36- 4
60	120.0	24.0	15.8	27.0		36- 8
Mean	116.2	25.1	15.9	28.4	*32.1	*2103.

RUN NUMBER FIVE.

Time	T_1	T_2	T_3	T_4	W_s	W_w
00	115.0	39.0	15.8	32.8		20-14
10	115.0	38.5	15.5	33.5		20-14
20	114.8	38.5	15.5	34.0		21- 2
30	115.0	38.0	15.2	34.0		20-14
40	115.5	37.0	15.2	33.2		20-14
50	114.0	37.0	15.1	33.0		20-15
60	113.0	36.0	15.1	33.0		21- 0
Mean	114.6	37.7	15.3	33.4	*48.8	*1292

RUN NUMBER SIX.

Time	T_1	T_2	T_3	T_4	W_s	W_w
00	105.5	31.0	13.5	39.0		37- 6
10	106.0	31.0	13.5	39.0		37- 6
20	107.5	30.0	13.4	38.0		37- 3
30	108.0	30.0	13.2	37.4		37- 0
40	109.5	29.5	13.2	36.8		37- 3
50	109.0	29.5	13.2	36.5		37- 3
60	108.0	29.0	13.2	36.0		37- 3
Mean	107.7	30.0	13.3	37.5	*63.5	*2232.

RUN NUMBER SEVEN.

Time	T_1	T_2	T_3	T_4	W_s	W_w
00	108.0	37.0	15.0	37.0		26-13
10	109.0	37.0	15.0	37.0		26-14
20	110.5	37.5	15.0	36.3		24- 6
30	112.0	35.0	14.5	35.5		29-12
40	110.5	30.0	14.8	35.5		30-15
50	111.5	30.5	14.7	35.3		31- 2
60	112.5	30.5	14.5	35.2		30-15
Mean	110.6	34.0	14.9	36.0	*55.40	*1719.

RUN NUMBER EIGHT.

Time	T_1	T_2	T_3	T_4	W_s	W_w
00	114.0	44.0	14.8	34.2		14- 4
10	114.0	44.5	14.8	34.2		14- 4
20	112.0	44.3	15.0	34.2		14- 4
30	114.5	44.5	15.0	34.2		14- 4
40	115.5	44.5	15.0	34.0		14- 2
50	115.3	44.8	15.0	34.3		14- 2
60	114.5	44.5	15.2	34.4		14- 5
Mean	115.0	44.5	15.0	34.25	*43.12	*854.

RUN NUMBER NINE.

Time	T_1	T_2	T_3	T_4	W_s	W_w
00	106.0	29.0	14.0	49.0		58- 0
10	105.0	29.0	14.0	48.0		58- 2
20	104.0	29.0	14.0	47.5		58- 2
30	105.0	28.5	14.0	47.0	43-14	58- 2
40	106.0	28.5	14.0	46.5		58- 6
50	106.0	28.5	14.0	46.0		58- 6
60	107.0	28.5	14.0	46.0	44- 2	58- 6
Mean	105.6	28.7	14.0	47.1	*88.00	*3493.

RUN NUMBER TEN.

Time	T_1	T_2	T_3	T_4	W_s	W_w
00	110.5	25.0	14.2	35.0		58- 8
10	113.5	25.8	14.3	32.8		59- 4
20	115.0	25.2	14.2	31.8		59- 6
30	116.0	24.8	14.3	31.7	45-10	59- 4
40	117.0	24.5	14.2	30.0		59- 4
50	118.5	24.2	13.8	30.0		59- 4
60	119.0	24.2	13.8	30.0	17- 4	59- 6
Mean	115.4	24.8	14.1	31.6	*62.9	*3540.

TABLE NUMBER ONE.

Run No.	$\frac{B.T.U.}{\#\text{steam}}$	V_s	V_w	T_s	T_w
1	1085.3	2180	5.50	72.70	22.45
2	1082.0	3240	5.27	76.50	27.00
3	1112.0	1280	4.68	72.25	20.45
4	1113.6	1232	6.85	72.30	20.50
5	1103.0	1862	4.20	74.52	26.10
6	1098.7	2385	7.24	72.65	21.65
7	1094.6	3091	5.58	73.27	24.45
8	1100.4	1650	2.78	74.61	29.75
9	1070.0	3285	11.36	76.35	21.35
10	1107.0	2418	11.50	73.50	19.45

This table gives the mean results obtained from the preceding runs, and shows the values used in computing the heat transfers, both actual and theoretical.

The first column gives the heat content in B.T.U.'s of a pound of steam at entrance.

The second and third columns give the mean velocity in centimeters per second of the steam and cooling water respectively.

The fourth and fifth columns give the mean temperature in degrees Centigrade of the steam and cooling water respectively.

TABLE NUMBER TWO.

Run No.	R_s	R_w	R_s-R_w	% Loss
1	4420	4220	200	4.53
2	6488	6150	338	5.21
3	2532	2445	87	3.44
4	2500	2425	75	3.00
5	3780	3670	110	2.91
6	4830	4700	130	2.68
7	4235	4130	105	2.49
8	3320	3190	130	3.92
9	6590	6470	120	1.82
10	4860	4795	55	1.13
			Mean	3.12

This table gives the thermal loss during each of the preceding runs. The first column gives the total quantity of heat given up by the steam in calories per second. Column two gives the total amount of heat gained by the cooling water. Column three gives the thermal loss in calories while column four gives the thermal loss in percentage of the entire system.

TABLE NUMBER THREE.

Run No.	R_W	F_1	F_2	R_W-F_2	$\frac{F_2 x 100}{R_W}$
1	4220	188	2690	1530	64.7
2	6150	221	2650	3500	40.3
3	2445	161	2750	-305	112.0
4	2425	150	2860	-435	117.0
5	3670	168	2398	1272	65.4
6	4700	198	2937	1763	62.5
7	4130	179	2612	1518	63.3
8	3190	147	2010	1180	63.0
9	6470	250	3650	2820	56.5
10	4795	215	3562	1233	74.4

This table shows the results obtained in each run by substitution in formulae F_1 and F_2. The first column gives the amount of heat actually transferred to the cooling water Columns two and three give the results obtained by substitution in formulae F_1 and F_2. Column four gives the difference between the actual heat transferred and the theoretical heat transferred by use of formula F_2. Column five gives the percentage of heat transferred as computed by formula F_2, compared to the actual heat transferred.

TABLE NUMBER FOUR.

Run No.	R_w	T_s'	F_3	R_w-F_3	%
1	4220	104.9	4410	-190	104.5
2	6150	105.0	4170	1980	67.8
3	2445	110.5	4520	-2075	184.0
4	2425	108.1	4530	-2405	199.0
5	3670	107.3	4020	-350	109.0
6	4700	103.8	4725	-25	100.5
7	4130	105.3	4330	-200	104.5
8	3190	107.5	3480	-290	109.0
9	6470	102.8	5420	1050	83.8
10	4795	107.7	5820	-1025	121.0

This table shows the results obtained in each run by substitution in formula F_3. The first column gives the actual heat transferred to the cooling water. Column two gives the mean temperature between 100 deg. C. and the entrance temperature of the steam. Column three gives the results obtained by the use of formula F3. Column four gives the difference between the result obtained from the formula and the actual heat transferred. Column four gives the result, expressed in percentage of the actual heat transfer, of the results obtained by use of formula F_3.

DISCUSSION OF RESULTS.

(A). General Formula.

The formula for the flow of heat through a given medium is similar to that for the flow of an electric current and may be obtained as follows:-

Let Q equal calories flowing per square centimeter.

A equal area in square centimeters of the surface through which the heat flows.

S equal time in seconds during flow.

C equal the thermal conductance of the medium, which is equal to the number of calories transmitted per second, per degree difference in temperature C., per square centimeter of area.

$t - t_1$ equal the temperature drop in degrees. Centigrade, between two planes cutting the medium, parallel to each other and perpendicular to the direction of heat flow.

Then Q equals $(t - t_1) \times A \times S \times C$.

In these experiments the time was taken as one second; t as the mean temperature within the steam tube; and t_1, as the mean temperature of the cooling water circulating around the steam tube.

Then $\qquad$ Q equals C x A x $(T_s - T_w)$.

This equation was used as the fundamental equation in determining the results obtained in these experiments.

In analyzing the situation in the heat transfer tube, only the following three transfers of heat were considered:

(1) Steam to brass.

(2) Through brass.

(3) Brass to cooling water.

The problem then was to find the total thermal conductance, C, as the other values could be measured, substitute in the formula and solve for Q.

From Richard's Metallurgical Calculations, the following formulae for heat transfer coefficients were obtained:

From gas to metal:

K_1 equals $.000028(2+\sqrt{V})$.

From metal to liquid:

K_2 equals $.000028(300+180\sqrt{V_1})$.

Through brass:

K_b equals $.2375/t$.

Where V and V_1 are the mean velocities of the gas and liquid respectively, and t is the thickness of the brass.

The conductivity of brass is very small compared to the others. Therefore it was assumed constant throughout the experiments. The pipe was .3175 cm. in thickness. Therefore the conductivity or

$$1/K_b \text{ equals } \frac{1}{.2375/.3175} \text{ equals } 1.34.$$

Hence the thermal conductance of the system was:

$$C \text{ equals } \frac{1}{1.34 + 1/K_1 + 1/K_2}$$

In each experiment the heat given up by the steam and the heat gained by the water, was determined. The difference gave the total loss of the system. This averaged about 3.12 per cent of heat given up by the steam and showed the system to have a thermal efficiency of about 97 per cent. These calculations also gave a means of verifying the use of C in the general formula, as it gave the <u>actual</u> heat gained by the liquid.

For each experiment the amount of heat transferred was calculated by each of the following formulae:

(F_1).

$$Q \text{ equals } \frac{A \times (T_S - T_W)}{1.34 + 1/.000028(300+180\sqrt{V}) + 1/.000028(2+\sqrt{V_1})}$$

(F_2).

$$Q \text{ equals } \frac{A \times (T_s - T_w)}{1.34 + 1/.000028(300+180\sqrt{V}) + 1/.000028(300+180\sqrt{V_1})}$$

(F_3)

$$Q \text{ equals } \frac{A \times (T_s - T_w)}{1.34 + 1/.000028(300+180\sqrt{V}) + 1/.000028(300+180\sqrt{V_1})}$$

(B). Discussion of Results Obtained from Use of Formula, F1.

In calculating the conductance in this formula, the following heat transfers were considered:

(1) Steam as a gas to metal.

(2) Through metal.

(3) From metal to liquid.

Hence, the corresponding formulae were used in computing these conductivities.

The mean velocity of the water could be determined accurately and this result was substituted in the equation.

The mean velocity of the steam could not be determined accurately. The entrance velocity of the superheated steam could be determined accutately, since it left the tube condensed entirely to water, which would mean a velocity ofzero, considered as a gas. The location of this point of zero velocity can not be determoned readily. This point of zero velocity depends on the quantity and temperature of

the cooling water and the quantity and entrance temperature of the superheated steam. Therefore, since it was thought that the change in velocity was abrupt rather than gradual, and since most of the heat was transferred during the condensation of the steam, the entrance velocity of the steam was assumed as the value for V_1 in the formula.

The temperature difference $T_s - T_w$ was computed by subtracting the mean temperature of the cooling water from the mean temperature of the steam. This mean temperature of the steam was taken as the mean value between the entrance temperature and the temperature of the condensate on exit. This was assuming that the lowering of the temperature was a constant ratio to the length of the heating surface. This assumption was incorrect, since it could not be proven that this ration was constant.

Assuming these values as stated, the heat transfer for each run was determined. It was found to be about only 4 per cent of the actual heat transferred. Therefore it was proven that the gas formula could not be applied to steam which is totally condensed during the flow. These results lead to the application of formula F_2.

(C). Discussion of Results Obtained by Use of Formula F_2.

In calculating the conductance in this formula, the following heat transfers were considered:

(1) Steam as a liquid, to metal.

(2) Through metal.

(3) From metal to liquid.

Therefore, the corresponding formulae were used in computing these conductivities.

As steam or any liquid which is superheated or saturated, condenses, the vapors will carry a thin film of liquid against the metal surface. Although this film is being constantly changed, there is always a film present whose temperature is that of the saturated vapors. This film should be considered as a part of the gas in considering the transfer of heat from the gas to the metal, although using the formula for liquids. That there is a heat transfer between the gas proper and the film there is no doubt. But it can not be determined experimentally. Hence it was assumed that the K in this case would be neglected. Since the thickness of this film is infinitessimal, the heat transfer through the film can not be determined. Therefore the formula for transfer of heat from a liquid was used, since the main transfer of heat was from a film of

liquid to a metal.

The other values were the same as in formula F_1. The results obtained show that this formula gave an average of 63 per cent of the actual heat transferred. These results justified the use of the formula F_2 and lead to the conclusion that the mean temperature of the steam was incorrect. This leads to the use of formula F_3.

(D). Discussion of Results Obtained by Use of Formula F_3.

In formulae F_1 and F_2, the T_s used was considered as the mean temperature between the entrance temperature of the steam as gas and the exit temperature of the steam as w water. This was stated to be an assumption, as the actual mean temperature was much higher.

Therefore in the present case the T_s, was assumed to be the mean temperature between the entrance temperature and the temperature of condensation or 100 deg. C. in the case of steam under atmospheric pressure. The use of the liquid formula was also continued in this case.

The results obtained from these calculations gave an average of 104 per ce t of the actual heat transferred. Although this result was a little high, it justified the

use of T_s, as explained above and the liquid formula. Since those experiments which showed a wide variation from the mean in both formula F_2 and F_3, are the same in both cases, it would indicate a probable error in the readings.

CONCLUSION.

From these experiments it has been shown, that the use of the gas formula for heat transfer from a gas, wetting the surface of the metal, to the metal, is incorrect. It also shows that by using the liquid formula for heat transfer and the mean temperature between the condensation temperature and the entrance temperature of the gas, the approximate correct values are obtained in this case. But owing to the limited nature of these experiments, the drawing of any general conclusion is forbidden.

In order to draw any conclusion along these lines it would be necessary to take a great number of runs, varying the conditions and length of the tube.

In the present experiments the steam entered as superheated steam and was totally condensed. This gives only one phase of the problem. The gas might enter merely saturated or even wet and only be partially condensed. But what ever the case might be, the gas would wet the surface of the metal and hence the existing gas formula for heat transfer does not apply. But a method has been shown, it is believed, whereby future experiments can be made to strengthen the conclusions drawn from these experiments.

These experiments were made in a preliminary manner, and for a conclusive proof it would be necessary to determine the temperature with greater accuracy. More accurate methods should be used in measuring the amount of water and condensed steam, as this data is of vital importance.

It is hoped that this work may be resumed, as the question of heat transfer is of great importance. Especially is this true in cooling coils where superheated and saturated gases are condensed. The existing formulae are incorrect except under given conditions. There is no reason, why a formula using the liquid formula for heat transfer, the mean temperature between the entrance and condensation temperature of the gas, and the entrance velocity of the gas, can not be determined. There might be a possible change in the numerical constants in the existing formula.

When such a formula has been found to which this class of gases belong, the subject of heat transfer in cooler coils will become a definite subject instead of being a vague, cut and try process as today.

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